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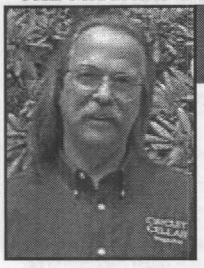

FROM THE BENCH

by Jeff Bachiochi

USB in Embedded Design (Part 2)

HIDmaker Converts an Application

Jeff makes converting to USB an attractive option with HIDmaker, a highly efficient program that does all the work for you. Creating USB software has never been easier.

Many of you will say they were too young, that they were struck down in the prime of their lives. What a shame, you'll say. They hadn't even reached the age of 50.

Are serial and parallel ports dead? I believe that nothing can really die unless it's forgotten. All of us have family and friends who have passed on, but we keep them alive by sporting their pictures on our walls, visiting gravesites, talking about them, and memorializing them in various public and private ways.

I remember the rumblings that TV would kill radio. (I can't imagine riding in my car without tunes.) But today's technology continues to assure radio's success via satellite. Although my kid's kids probably won't even know what serial and parallel ports are, that's at least a decade away. Although it's getting tougher to foresee what the future holds, I doubt that they will totally disappear anytime soon. It's more likely that they will become obsolete because of nonsupport in much the same way DOS has been neglected (although still used by some).

"If it ain't broke, don't fix it." I'm a big believer in that statement. But I also understand that much of the world economy's growth is based on the development of new technology and the harnessing of its potential. If we stand still, we run the risk of falling behind. Do you want to run that risk?

BECOME A USB CONVERT

If you aren't convinced that you need USB after last month's column, you're standing still. Last time, I briefly discussed the reasons for the development of USB and how you can benefit from its implementation. You observed the physical attributes of the USB connection and how a USB device makes itself known to the host through enumeration. Furthermore, I explained how tiered interconnections allow the host to communicate with each USB device on a one-to-one basis using data packets stuffed into 1-ms frames. I also introduced a previously designed X10 project.

X10 uses the AC power lines in your home to transmit control codes to specially designed outlets that respond to the codes. X10 codes can turn on and off appliance modules (relay-based). They also turn on and off—as well as dim and brighten—lamp modules (triac-based). These modules can be purchased in an AC outlet form factor or as plug-in modules.

The project consists of a serially connected dongle, which translates serial X10 commands into the appropriate control signals to drive a TW523 isolated power line interface. A PC application feeds user-selected X10 commands, as TX serial data, to the dongle while monitoring the RX serial input for X10 commands received from the power line.

Any X10 command can be sent by transferring 3 bytes (HouseCode, UnitFunctionCode, and RepeatCode) to the dongle over the serial interface. An X10 command seen by the TW523 on the power line is returned to the application by the dongle transferring 2 bytes (HouseCode and UnitFunctionCode) back via the serial interface.

To replace the serial interface with a USB equivalent requires hardware and software design changes. These changes, which are not minor, may require choosing a new processor for your design.

HARDWARE CHANGES

The most visually dramatic changes to a project are physical ones. The area needed for a USB interface is considerably less than that of serial and parallel ports. Besides the connector size shrinking to about 25% of a DB25, only a few discrete parts are needed instead of level shifters or buffers. You can free up a few square inches of real estate on your PCB. Furthermore, you can really luck out if the manufacturer of your microcontroller makes a version with a USB peripheral. More and more manufacturers are jumping on this bandwagon. If not, you may be able to add a USB interface chip (e.g., the Philips ISP110x) to your micro, assuming it has the horsepower and buffers to support all of the necessary USB functions. The great part about using a micro integrated with USB is that all the low-level stuff is done for you.

USB hardware handles detecting and decoding incoming packets. It determines which transactions to ignore (no matching address) and which to react to, flagging the type for endpoint 0. Incoming data is stored in the appropriate buffer or flagged as an error. The number of bytes received and the data-toggle state is stored. The hardware calculates and compares CRC values, and takes the appropriate action on errors. It automatically sends any necessary handshaking to the host and triggers an interrupt for the firmware to take action. Outgoing data is encoded for transmission along with the byte count and data-toggle code.

The hardware also calculates a CRC and appends it to the data packet. After

receiving a handshake from the host, it triggers an interrupt for the firmware to take action. I'm sure you'll concede that this functioning is something to be avoided if possible. You can sidestep this entirely by designing with a microcontroller that has USB support.

SOFTWARE CHANGES

Data transmission via a serial port requires the conversion of data through hardware or software into asynchronous or synchronous bitstreams. The two devices are configured for the same data format so that what goes in one end comes out the other end. They may use hardware, software, or no flow control. These factors must be agreed to prior to any communication; for the most part, they cannot be identified through the connection itself.

Data transmission via parallel ports moves data in byte-sized transfers using eight parallel data paths. Although potentially 10 times faster than serial, hardware handshaking is done on a byte-by-byte basis, which slows everything down.

The original parallel port is unidirectional and—discounting the 5 bits of status inputs, which are often used for inputting nibble data—is not meant to be a bidirectional device. This led to the bidirectional port (SPP), the enhanced parallel port (EPP) for speedier nonprinter devices, and the extended capabilities port (ECP) for speedier printing devices. Which do you have? Truth be told, unless you are using an older system, you probably have support for all of them, but it is still half-duplex.

Although similar to synchronous serial, a USB host can obtain everything it needs to know about a device through the connection. Therefore, you don't have to know anything about a device just to make a connection to it. It's easy for you (as a user), but tough on the designer.

A special device descriptor is the key to each device. This is the biggest stumbling block for a designer. The hardware handles much of the work. For the most part, after putting together the device descriptors, it is simply a mater of managing your data in and out of the endpoint buffers.

Handling this data takes some thought, however, particularly because of the way USB operates. Your project may be used to sending data whenever necessary to the application. Under USB rules, the host must ask for data before a device can send it. You're in trouble unless you have the resources to hold the data until it's asked for.

Last month I covered the designed data throughput of USB. Now is a good time to cover the four types of transfers (control, interrupt, bulk, and isochronous) because each has different throughputs (see Table 1).

Transfer type	Maximum data transfer rate per endpoint (KB/s) (data payload/transfer = maximum packet size for the speed)		
	Low speed	Full speed	High speed
Control	24	832	15,872
Interrupt	0.8	64	24,576
Bulk	N/A	1216	53,248
Isochronous	N/A	1023	24,576

Table 1—*A wide range of throughput is available depending on the bus speed and transfer type that you select for your design. Note that bulk and isochronous types can't be used with the low-speed bus interface.*

The all-important enumeration process is handled with control transfers. The host allocates between 10% and 20% of a frame to control transfers. Although all enumeration begins with endpoint 0, control transfers are not limited to endpoint 0 or enumeration. A control transfer can be used at any time as defined by any class (or vendor).

Don't be fooled by its name, the interrupt-type transfer does not cause an interrupt; instead, it is guaranteed to occur within a certain amount of time (more like interrupt latency). The interrupt transfer is used where you don't want to miss a key press, mouse move, or any other real-time interaction event. (The Windows predefined HID driver supports this mode.) This type of transfer also requires separate in and out pipes for data. Although attempts by the host are guaranteed, it's up to the device to be ready and to ensure any throughput. The latency time is defined in the device's descriptor table.

Bulk transfers are similar to interrupt transfers, except there is no guarantee on when the data will start or finish. They are plugged into frames whenever there is room. This type of transfer also requires separate in and out pipes for data. With no USB traffic, a bulk transfer can fill the full frame. However, if other USB transfers fill the frames, a bulk transmission is held off. Bulk transfers are generally limited to functions that aren't time critical (e.g., printing and file transfers).

The isochronous transfer is similar to an interrupt transfer in that there is a guarantee. Here the isochronous transfer requests a specific bandwidth. The host must calculate what bandwidth it has to offer before it can accept and configure an isochronous pipe. Success depends on which other devices are already on the bus. This type of transfer also requires separate in and out pipes for data. You can see that allocating bandwidth ensures the data gets there; however, there is no plan for resending corrupted data. Therefore, this type of transfer is used where the application can tolerate small errors (streaming audio). The bandwidth requirements are defined in the device's descriptor table.

DEVICE CLASSES

If you could gather all the USB devices out there (as well as those that haven't been designed yet) and separate them into groups with similar characteristics, you could define classes of devices, which would include the following: the HUB device, audio device, chip/smartcard interface device, communication device, content security device, device firmware upgrade, human interface device (HID), IrDA bridge, mass storage, printer, and imaging. The list is continually growing.

As you can imagine, generic drivers don't hack it for most peripherals. There is the necessity for special drivers to be written to handle each of these devices, even those within the same class. After the host has received a device descriptor table through enumeration, it can search its .INF (or other files) for a matching class and device driver. If necessary, the host asks you for the appropriate drivers. (That's if the device is new to the system.)

Windows has a generic driver for the HID class. (Try searching for hiddev.inf; it can be viewed with Notepad.) Because HIDs have a generic class driver, designers can make

their lives less complicated by trying to design for this class.

HUMAN INTERFACE DEVICE

As its name suggests, a HID has to do with devices that interact with you. This covers numerous input and output devices (e.g., keyboard, mouse, steering wheel, rumble pack, and joystick). Many monitors have an embedded HID device, which is used for screen configuration rather than video. In actuality, a device does not need to interface with you to be a HID. If your device's data requirement fits within the HID class's specifications, you're golden.

My conversion project fits within this specification. I needed to be able to transfer 3 bytes out of the PC to the interface or 2 bytes into the PC from the interface.

X10 transmissions are slow because they are based on 60-Hz zero-crossings. X10 commands require about 0.5 s (22 60-Hz cycles) to be completed on the power line, so you don't need to be worried about exceeding available frame times. As far as sending data from the PC, the interface is designed to transmit an acknowledgement of received data (loop back); therefore, loss of data because the interface is busy is handled by the host application expecting looped-back data.

On the interface side, I had to create the appropriate descriptor tables and change the interface application code to make use of the USB hardware in the micro. Assuming the generic HID driver is usable on the host (PC), I had to change the data exchange routines in the application from serial to USB.

HIDmaker

Trace Systems looked into the future and built a product to get you up and running quickly with USB.

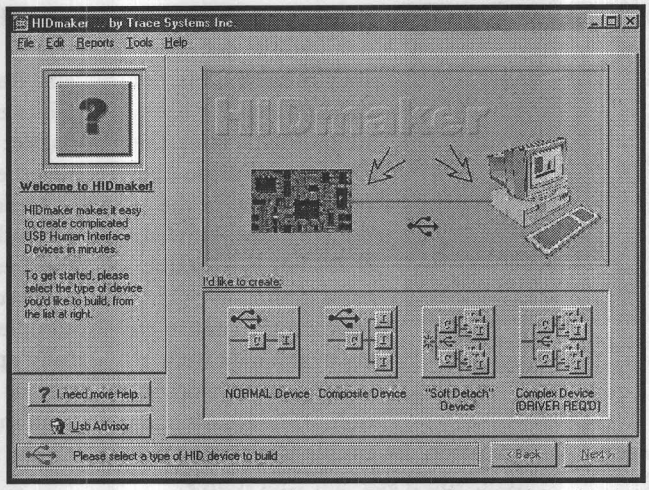

Photo 1—*HIDmaker simultaneously generates programs for the peripheral device and the PC. The programs can communicate with each other over the USB via the HID class. Even complex interfaces can be modeled with HIDmaker.*

HIDmaker was designed for use with the HID class, so no device driver programming is required. You get all the benefits of USB with less work than RS-232 serial because it does the hard work for you!

HIDmaker creates two documented programs—one for the PC and one for your microprocessor—that already communicate with each other using USB. The programs, which are built around the data that you describe, are written for Microchip USB PICs in your choice of environments: PicBasic Pro, Microchip MPASM, CCS C, or Hi-Tech PICC. On the PC side, HIDmaker supports Visual Basic 6, Delphi, and C++ Builder. (These environments are the first to be supported by HIDmaker with other microcontrollers and manufacturers to follow.) It's a perfect fit for this project because I originally used a PIC (and PicBasic) for the device and Visual Basic for the application.

Photo 1 shows the opening HIDmaker screen. The program is set up in the familiar Wizard style. After you add the required information to each page, click the Next button to move on. You can save the project file and exit any page. Loading the project file brings you back to where you left off.

To begin the HIDmaker process, select a device type. This tells HIDmaker how complicated your new device is. The device in this project is simple. More complex devices have multiple, independent types of functionality (a combination keyboard/mouse).

On the second page, you name your project and select a location for the files that HIDmaker will produce. You also add information like the vendor ID and project ID, which are required by Windows to identify your device. Any device sold commercially must have a vendor ID from USB Implementers Forum.

Notice the various boxes labeled "Use in F/W." If checked, the optional information can be placed in device firmware by HIDmaker to be discovered through enumeration by the host.

HIDmaker offers two types of help. The "I need more help..." button provides context-sensitive help for using the controls that are currently visible on the screen. The USB Advisor button gives advice about appropriate inputs, what the inputs mean, and how they relate to the process.

The third page gets down to the nitty-gritty. I've already indicated that this is a normal device. As such, it has a single configuration. As you can see in Photo 2, most entries already have selections;

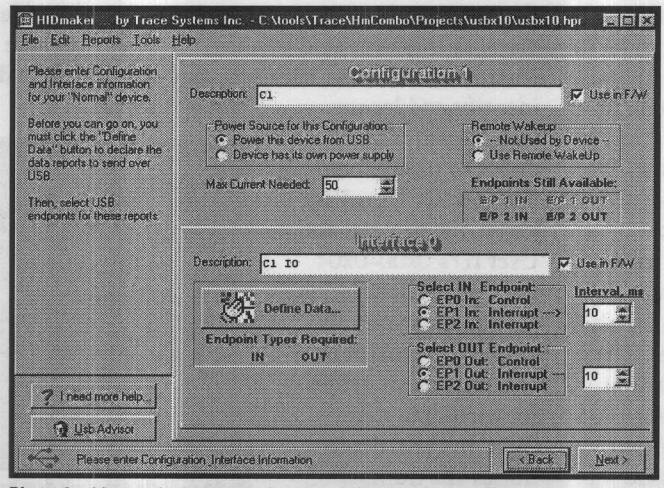

Photo 2—*Most projects can use the normal device selection. They need a single interface defined. Complex devices require you to define an interface scheme for each configuration.*

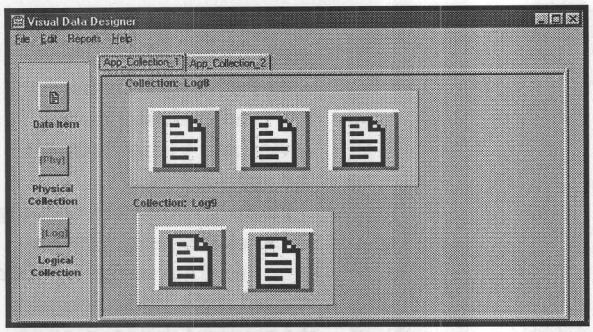

Photo 3—*Data items can be placed in logical or physical collections. Collections aid in understanding how the data items are used but do not affect how the data is actually handled.*

these are the most common usages, but alternatives can be selected.

If you want the USB interface to supply power to the device, you must also indicate the device's current consumption. Because the total current available through the USB interface is limited, the host uses this value during enumeration to determine if there is available current to allocate to the device.

As you know, low-speed devices are limited to two kinds of transfer types, control and interrupt. I chose to use interrupt transfers to ensure periodic transfers. Because I need data to go in both directions, I choose EndPoint1 IN and EndPoint1 OUT. The host creates separate pipes (virtual connections) between it and the device endpoints based on this information. Note that you also get to indicate how often you want each transfer to take place.

Only one more bit of information must be defined: the data that will be transferred. Clicking on the Define Data button brings up the fourth and final page (see Photo 3). The data for this project consists of three values going to the device (using out endpoint 1) and two values going to the PC (using in endpoint 1). This page has three buttons on the left and a large drawing area. Use this page to create data items—one for each variable used in each pipe.

The two lower icons on the left—Physical Collection and Logical Collection—help you indicate which data items are grouped together. They can be placed in the drawing area as placemats for the data items. For instance, you may want to use two Logical Collection placemats, one for the three out data items and one for the two in data items. These don't actually affect how the data will be defined; they merely aid in documentation. For each item of data, click the Data Item button and place an icon in the drawing area. Now all that's left is to define each item.

When the mouse hovers over a data item, a pop-up shows a description of the item's configuration. By double-clicking on the item, you'll see that data item's editable properties (see Photo 4). I changed each data item's name to the variable name I use in the applications (again, to help with documentation).

The data type must be selected based on the endpoint, either input or output, for this project. The usage info consists of a combination of two numbers: a Usage Page number and a Usage ID number, which is the number of an item in the Usage Page. A Usage ID represents some particular function or feature of a device, and the Usage Page is a collection of Usage IDs that belong in the same category. The HID usage table's specification defines and documents nearly 1600 combinations of Usage Page and Usage ID. Click the Browse Usages button to pick from a list of all the standard usages that were recently defined as well as a modest number of Vendor Defined usages.

It is important that every data item you define has a distinct Usage ID; this is the only way that the HID class, as implemented by the Microsoft Windows HID API, can identify and locate your data items. I chose to use the vendor-specific User Page (0xFF, the default) and User ID's 0x00–0x04 for the five data items. Notice that you can define the maximum and minimum values for each data item. This, in turn, determines the number of bits necessary to define your item.

My HouseCodeIn/Out items require 8 bits. The UnitFunctionCodeIn/Out and RepeatOut items only require 5 bits each. (The transferred USB data packet contains data items packed together to save every bit possible.)

Although this project is fairly simple and the default values are used in most cases, you can see that the data properties offered are both flexible and complex. HIDmaker's guidance isn't fully appreciated until you look at the output generated by compiling and building sample applications based on all the input that you complete.

HIDmaker DEVICE OUTPUT

After you have fully defined your device, its data, and its interface, HIDmaker can work its magic. Select the environments that you want HIDmaker to generate output for (I used PicBasic Pro and Visual Basic), and in seconds you'll receive a list of all the output files for both the peripheral and the host. You can peruse the files before exiting HIDmaker. You may download the files from the *Circuit Cellar* ftp site.

On the peripheral side, HIDmaker generates two main files (nine files in all for this project). First, descript.asm holds all of the descriptor tables defined from the information entered in HIDmaker. Then there is USBX10_M.bas, which is this project's PicBasic Pro application file. The following four files are project-independent. Three Microchip files—usb_ch9.asm, usb_defs.inc, and hid-class.asm—support the PIC USB parts. One file, usbdesc.asm, lists a number of include files specific to PicBasic Pro.

The descript.asm file, which is cer-

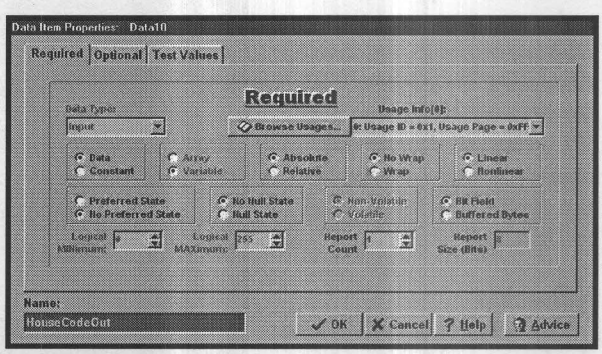

Photo 4—*Although each data item must be fully defined, many default selections can be used. Take some time to make sure your data will be handled with the respect it deserves.*

tainly the most important, contains all of the tables the host reads during enumeration to gain the ultimate knowledge of your device. For this particular project, it contains a device descriptor table, configuration descriptor, interface descriptor, HID descriptor, endpoint descriptor (for EndPoint1In), endpoint descriptor (for EndPoint1Out), and report descriptor. That's not to mention the string descriptors as defined in HIDmaker (e.g., language ID, manufacturer, product name, serial number, and other option strings).

Using Microchip's IDE and PicBasic Pro, I compiled the project files into a hex file, which is used to program a PIC16C745. Let's take a quick look at what HIDmaker built for this simple application.

HIDmaker creates a USB interface capable of moving defined data. In this case it does this by setting up an application to pass three data items from the host and collect two data items from the device using a USB connection. After some initialization, the application proceeds to a main loop where the USBIN command checks to see if there is any out endpoint 1 data available. If so, it retrieves and unpacks the data. Otherwise, it goes on.

In the second part of the loop, the out endpoint 1 data items are set to test values (initially defined in the define data section of HIDmaker), and a flag is set to indicate that data is ready to send. The data is packetized and the USBOUT command is executed, which sends the data to the USB in endpoint 1 buffer if it is free. (Otherwise, it tries again.) Then it's back to the main loop.

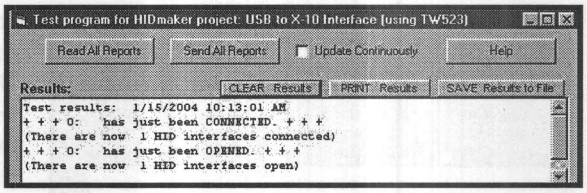

Photo 5—*HIDmaker creates device and PC applications that complement one another. Here the PC application demonstrates that it has succeeded in providing a working USB connection by allowing you to pass your defined data to and from the PC.*

Notice that this application passes data but there is no apparent check on the data. This could be easily modified in this case so that the data that comes in is used for the data that goes out. But this is not necessary because there are ways to see the data inside the PIC. At this point, if everything was done correctly, the PIC with the necessary USB circuitry will enumerate when it's plugged into a USB port on the PC (see Figure 1).

HIDmaker HOST OUTPUT

On the host side, HIDmaker creates three main files and a bevy of support files (11 files in all for this project). USBX10_M.frm is the main program module. Adding this form to a project enables the HIDagentX object, which is used for a USB interface. It is similar to using an MSComm object for a serial interface.

The USBX10_L.cls class module library file handles the variables and functions that make direct interfacing with the HID system calls unnecessary. The OneHidVar.cls class module file represents one USB HID data item or variable with all its attributes. Additional modules are created by HIDmaker, PC_Consts.bas (a file of expected device strings) plus error checking, and context help support files.

You can create a project .EXE file for the HIDmaker-created application using Visual Basic IDE, or you can run it in Debug mode from the IDE. Photo 5 gives you a quick picture of what is going on. The application will not run if it doesn't find a matching device enumerated on the USB bus. Assuming it does, the application pops up a window and shows that it has found a device. You can use the Send All Reports and Read All Reports buttons to test the communication to and from the attached device. The transferred data, which is hard coded into both applications (the host PC and the device microcontroller), originates from the HIDmaker define data steps.

Unless you can see into the microcontroller, you won't know if the correct data has arrived. However, you will see the data arriving from the device displayed in the host application program. At that point HIDmaker has proven its success. You can take these applications and integrate them with your own code. But wait, HIDmaker is still of use.

OPTIONAL TOOLS

Remember how I said that you couldn't see inside the micro? Well, if Microchip had its act together, they would have the USB devices available in flash memory and the ICD in-circuit debugger could be used to look at the microcontroller's registers.

Trace Systems has added hooks within its code to allow messages to be output through a serial port on the microcontroller. (Isn't it ironic to use a serial port to debug its replacement?) You can use this technique to log messages (including any values) at any point in the application, so you can see the values received from the application. In fact, if for some reason your device doesn't enumerate correctly, this can provide you with feedback about the failure's location.

Enumeration failure can be the biggest source of headaches for a designer. Although HIDmaker generates working code for you, if enumeration fails, HIDmaker offers suggestions about potential problems.

USBwatch is a terminal-style application that interprets tokens sent by the microcontroller out of the debugging serial port. Tokens are used to reduce serial traffic to a minimum. The

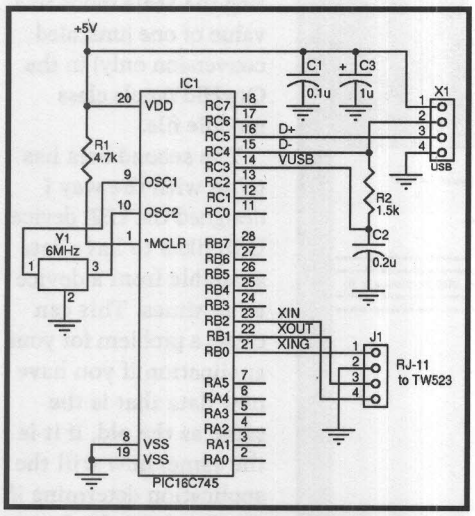

Figure 1—*The PIC16C745 microcontroller has USB support for version 1.1. The interface is simple and can be powered from the USB bus. The microcontroller can apply an internal phase-locked loop to operate at 24 MHz using an external 6-MHz crystal.*

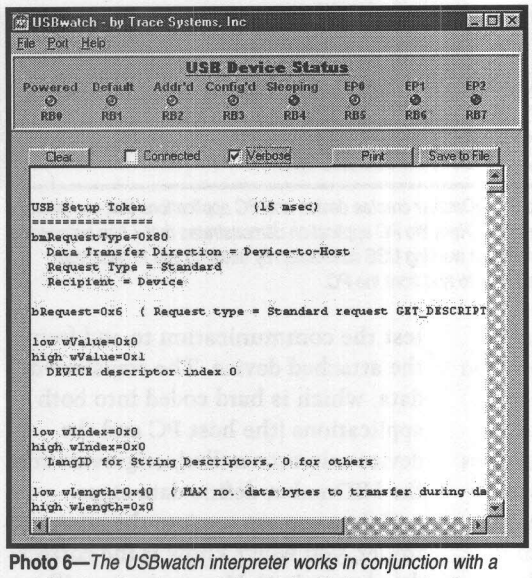

Photo 6—*The USBwatch interpreter works in conjunction with a serial port on the microcontroller. Embedded commands allow you to see what's happening inside the microcontroller. You determine the information reported by enabling the hooks within the HIDmaker-generated code.*

USBwatch application expands the tokens back into real English text. Note that there are a number of indicators above the text window in Photo 6. These help determine the status of enumeration and the present endpoint in use.

From the PC side, you can investigate all USB devices using the AnyHID application, which shows all of the USB devices (except hubs and the system's keyboard and mouse). When you choose a device, AnyHID will tell you all about it by reading the descriptor tables from the selected device (see Photo 7). Because the descriptors contain information about each data item, AnyHID is presents you with the opportunity to configure a data packet to send to the device and to receive and interpret requested data.

TIME TO CONVERT

HIDmaker's microprocessor test application code is well documented and uses embedded comments to suggest where you might add your application code. PicBasic's `USBIn1` command retrieves any received USB output data packet while HIDmaker's code unpacks the data and sets the HandleEp1Rcv flag when data is available to you from the host. In a similar fashion, you set the EP1XmtDataReady flag when you have data to send to the host. HIDmaker's code packs your data and uses the PicBasic `USBOut1` command to send USB packets to the host when it requests data.

On the PC side, I opened my serial-based application in Visual Basic. All of the modules and class modules that HIDmaker created for the test application are added to the project. The MSComm object on my main form (Form1) was replaced with the HIDAgentX object. The FRMPROPS.FRM form was deleted because this is the MSComm popup form that allows you to set the serial port properties. The project was saved as USBX10.

Next, the code in the USBX10_M.frm form that produced the test application form had to be eliminated or the necessary code had to be copied from the USBX10_M.frm form to Form1. I chose the latter.

Gone are four routines that deal with the serial port, opening and closing the serial port, and sending characters to and getting characters from MSComm. In their place HIDagent's routines become the low-level engine that does all the hard work of opening HID devices, accessing HID data items, and packing and unpacking reports. After HIDagent has detected, identified, and bound itself to an enumerated device, its runtime events become accessible.

The `Sub ReadRpts()` routine periodically transfers data items from an input report. I placed code within this routine to test for new data, manipulate it, and perform an update on the form using the received X10 command (new data). To send an X10 command, I used the `CmdSendX10_Click()` event to assign values to the data items before requesting a `WriteAllReports`.

SALVATION AT LAST

The finished application shows little sign of change (see Photo 8). Two areas of concern popped up while using HIDmaker to help convert the application. First, thanks to Microsoft's wisdom, all data is treated as signed unless specifically told not to. This results in a popup asking if this should be ignored each time the program is executed. The Windows routine is avoided by setting the Scale mode to a value of one (unscaled conversion only) in the OneHidVar.cls class module file.

The second area has to do with the way I designed the USB device. USB likes to have data available from a device at all times. This can cause a problem for your application if you have new data that is the same as the old. If it is the same, how will the application determine if the data from the device is old or new? Instead of adding complexity using some kind of flag

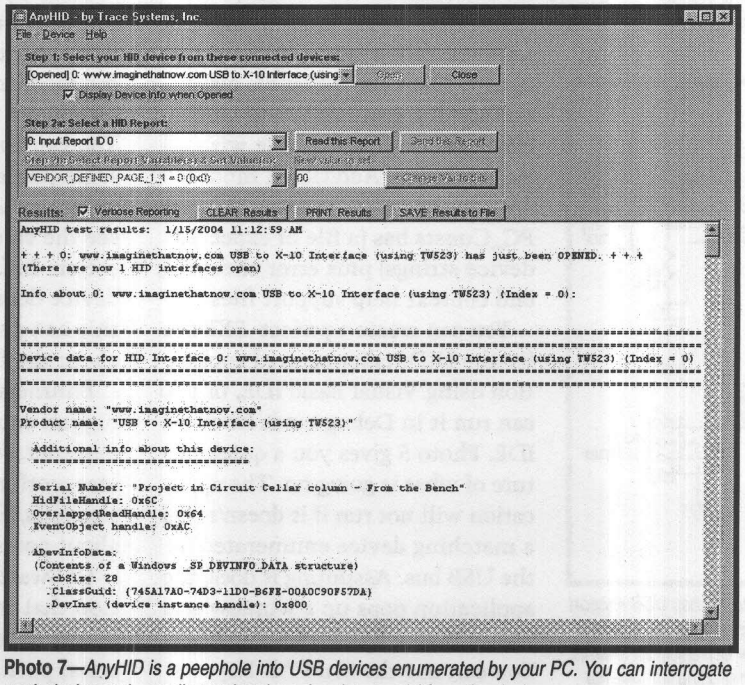

Photo 7—*AnyHID is a peephole into USB devices enumerated by your PC. You can interrogate each device and actually send and receive data to and from the device.*

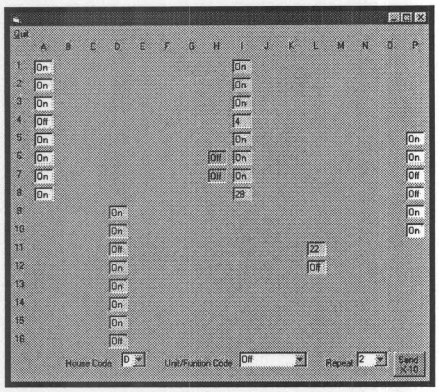

Photo 8—*With the conversion now complete, the Visual Basic application originally written using a serial port interface operates using the new USB interface. Your customer may never notice the difference.*

exchange, I don't provide data to the USB port unless it is new. So, most of the time when the host asks for data, the device will not answer and the host will timeout after a default (default = 5000, 5 s). This causes some rather nasty application lags during periods of no new data (most of the time). Shortening the USB timeout property to 100 ms in the `CreateHidObjects` routine eliminated it.

Using USB for I/O is no longer as easy as writing to a port. To become a user-friendly interface, USB has made the designer's job extremely complicated. Luckily, manufacturers are realizing they need to help reduce the burden. Trace Systems's package shortens the learning curve. HIDmaker, along with its optional tools AnyHID and USBwatch, provides the support needed to make USB come alive for the designer. Trace Systems knows what you need, and it supplies plenty of support documentation like the USB, HID class, and usage table specifications.

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PROJECT FILES

To download the code, go to ftp.circuitcellar.com/pub/Circuit_Cellar/2004/166.

RESOURCES

J. Axelson, *USB Complete: Everything You Need to Develop Custom USB Peripherals*, 2nd ed., Lakeview Research, Madison, WI, 2001.

USB Implementers Forum, www.usb.org.

SOURCES

PIC16C745 Microcontroller with built-in USB support
Microchip Technology, Inc.
(480) 792-7200
www.microchip.com

PicBasic Pro
microEngineering Labs
(719) 520-5323
www.melabs.com

HIDmaker
Trace Systems Inc.
www.tracesystemsinc.com

TW523 X10 two-way interface
www.X10.com